BLIND INTERFERENCE SUPPRESSION AND POWER ADJUSTMENT WITH ALTERNATING OPTIMIZATION FOR COOPERATIVE DS-CDMA NETWORKS

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ABSTRACT

This work presents blind joint interference suppression and power allocation algorithms for DS-CDMA networks with multiple relays and decode and forward protocols. A scheme for joint allocation of power levels across the relays subject to group-based power constraints and the design of linear receivers for interference suppression is proposed. A code-constrained constant modulus (CCM) design for the receive filters and the power allocation vectors is devised along with a blind channel estimator. In order to solve the proposed optimization efficiently, an alternating optimization strategy is presented with recursive least squares (RLS)-type algorithms for estimating the parameters of the receiver, the power allocation and the channels. Simulations show that the proposed algorithms obtain significant gains in capacity and performance over existing schemes.

Index Terms— DS-CDMA, cooperative systems, optimization methods, blind algorithms, resource allocation.

1. INTRODUCTION

Multi-antenna wireless communication systems can exploit the spatial diversity in wireless channels, mitigating the effects of fading and enhancing their performance. Due to size and cost of mobile terminals, it is usually impractical to equip them with multiple antennas. However, spatial diversity gains can be obtained when single-antenna terminals establish a distributed antenna array via cooperation [1]-[2]. In a cooperative system, terminals or users relay signals to each other in order to propagate redundant copies of the same signals to the destination user or terminal. To this end, the designer must use a cooperation protocol such as amplify-and-forward (AF) [2] and decode-and-forward (DF) [2, 3].

The use of cooperative diversity and multiple hops is key for networks that need to increase the link reliability and extend their coverage [2]. Prior work on cooperative multiuser DS-CDMA networks has focused on the assessment of the impact of multiple access interference (MAI) and intersymbol interference (ISI), the problem of partner selection [3, 6], the bit error rate (BER) and outage performance analyses [7], resource allocation [4, 5] and training-based joint power allocation and interference mitigation strategies [11, 12]. However, these strategies require a significant amount of training data and signalling, decreasing substantially the spectral efficiency of cooperative networks. This problem is central to ad-hoc and sensor networks [13] that employ spread spectrum systems and multiple hops. This calls for methods to decrease the amount of signalling and training in cooperative wireless networks.

In this work, blind joint interference suppression and power allocation algorithms for DS-CDMA networks with multiple relays and DF protocols are proposed. A blind scheme that jointly considers the power allocation across the relays subject to group-based power constraints and the design of linear receivers for interference suppression is proposed. The idea of a group-based power allocation constraint is shown to yield close to optimal performance, while keeping the signalling and complexity requirements low. A code-constrained constant modulus (CCM) design [16]-[20] for the receive filters and the power allocation vectors is developed along with a blind channel estimator. The CCM design is adopted as it achieves a performance close to training-based algorithms. In order to solve the proposed

optimization problem efficiently, an alternating optimization strategy is presented with recursive least squares (RLS)-type algorithms for estimating the parameters of the receiver, the power allocation and the channels.

The paper is organized as follows. Section 2 describes a cooperative DS-CDMA system model with multiple relays. Section 3 formulates the problem, the CCM design of the receive filters and the power allocation vectors subject to a group-based power allocation constraint, and a blind channel estimator. Section 4 presents the alternating optimization strategy along with RLS-type algorithms for estimating the parameters of the receiver, the power allocation and the channels. Section 5 presents and discusses the simulation results and Section 6 draws the conclusions of this work.

2. COOPERATIVE DS-CDMA NETWORK MODEL

Consider a synchronous DS-CDMA network with multipath channels, QPSK modulation, K users, N chips per symbol and L as the maximum number of propagation paths for each link. The network is equipped with a DF protocol that allows communication in multiple hops using n_r fixed relays in a repetitive fashion. We assume that the source node or terminal transmits data organized in packets with P symbols, the system can coordinate cooperative transmissions, and the linear receivers at the relay and destination terminals are synchronized with their desired signals. The received signals are filtered by a matched filter, sampled at chip rate and organized into $M \times 1$ vectors $\boldsymbol{r}_{sd}[m_1]$, $\boldsymbol{r}_{sr_i}[m_1]$ and $\boldsymbol{r}_{r_id}[m_j]$, which describe the signal received from the source to the destination, the source to the relays, and the relays to the destination, respectively,

$$
\begin{aligned}
\boldsymbol{r}_{sd}[m_1] &= \sum_{k=1}^{K} a_{sd}^k[m_1]\boldsymbol{C}_k\boldsymbol{h}_{sd,k}[m_1]b_k[m_1] \\
&\quad + \boldsymbol{\eta}_{sd}[m_1] + \boldsymbol{n}_{sd}[m_1], \\
\boldsymbol{r}_{sr_j}[m_1] &= \sum_{k=1}^{K} a_{sr_j}^k[m_1]\boldsymbol{C}_k\boldsymbol{h}_{sr_j,k}[m_1]b_k[m_1] \\
&\quad + \boldsymbol{\eta}_{sr_j}[m_1] + \boldsymbol{n}_{sr_j}[m_1], \\
\boldsymbol{r}_{r_jd}[m_j] &= \sum_{k=1}^{K} a_{r_jd}^k[m_j]\boldsymbol{C}_k\boldsymbol{h}_{r_jd,k}[m_j]\tilde{b}_k[m_j] \\
&\quad + \boldsymbol{\eta}_{r_jd}[m_j] + \boldsymbol{n}_{r_jd}[m_j],
\end{aligned}
\tag{1}
$$

where $M = N+L-1$, $m_j = (j-1)P+1, \ldots, jP$, $i = 1, \ldots, P$, $j = 1 \ldots, n_p$, P is the number of symbols in the packet, $n_p = n_r + 1$ is the number of transmission phases or hops, n_r is the number of relays, m_j is the index of original and relayed signals, $\boldsymbol{n}_{sd}[m_1]$, $\boldsymbol{n}_{sr_j}[m_1]$ and $\boldsymbol{n}_{r_jd}[m_j]$ are zero mean complex Gaussian vectors with variance σ^2 generated at the receivers of the destination and the relays from different links, and the vectors $\boldsymbol{\eta}_{sd}[m_1]$, $\boldsymbol{\eta}_{sr_j}[m_1]$ and $\boldsymbol{\eta}_{r_jd}[m_j]$ represent the intersymbol interference (ISI). The quantities $b_k[m_1]$ and $\tilde{b}_k[m_j]$ represent the original and reconstructed symbols by the DF protocol at the relays, respectively. The amplitudes of the source to destination, source to relay and relay to

destination links for user k are denoted by $a_{sd}^k[m_1]$, $a_{sr_j}^k[m_1]$ and $a_{r_jd}^k[m_j]$, respectively. The $M \times L$ matrix C_k contains versions of the signature sequences of each user shifted down by one position at each column as described by

$$
C_k = \begin{bmatrix} c_k(1) & & \mathbf{0} \\ \vdots & \ddots & c_k(1) \\ c_k(N) & & \vdots \\ \mathbf{0} & \ddots & c_k(N) \end{bmatrix}, \tag{2}
$$

where $c_k = [c_k(1), \ c_k(2), \ \ldots, \ c_k(N)]$ stands for the signature sequence of user k, the $L \times 1$ channel vectors from source to destination, source to relay, and relay to destination are $h_{sd,k}[m_1]$, $h_{sr_j,k}[m_1]$, $h_{r_jd,k}[m_j]$, respectively. By collecting the data vectors in (1) (including the links from relays to the destination) into a $(n_r + 1)M \times 1$ received vector at the destination we obtain

$$
\begin{bmatrix} r_{sd}[m_1] \\ r_{r_1d}[m_2] \\ \vdots \\ r_{r_{n_r}d}[m_{n_p}] \end{bmatrix} = \begin{bmatrix} \sum_{k=1}^K a_{sd}^k[m_1] C_k h_{sd,k}[m_1] b_k[m_1] \\ \sum_{k=1}^K a_{r_1d}^k[m_2] C_k h_{r_1d,k}[m_2] \tilde{b}_k^{r_1d}[m_2] \\ \vdots \\ \sum_{k=1}^K a_{r_{n_r}d}^k[m_{n_p}] C_k h_{r_{n_r}d,k}[m_{n_p}] \tilde{b}_k^{r_{n_r}d}[m_{n_p}] \end{bmatrix}
$$
$$
+ \boldsymbol{\eta}[i] + \boldsymbol{n}[i] \tag{3}
$$

Rewriting the above signals in a compact form yields

$$
r[i] = \sum_{k=1}^K \widetilde{B}_k[i] \widetilde{A}_k[i] \widetilde{C}_k h_k[i] + \boldsymbol{\eta}[i] + \boldsymbol{n}[i]
$$
$$
= \sum_{k=1}^K P_k[i] B_k[i] a_k[i] + \boldsymbol{\eta}[i] + \boldsymbol{n}[i], \tag{4}
$$

where the $(n_r+1)M \times (n_r+1)L$ matrix $\widetilde{C}_k = \mathrm{diag}\{C_k \ldots C_k\}$ contains copies of C_k shifted down by M positions for each group of L columns and zeros elsewhere. The $(n_r+1)L \times 1$ vector $h_k[i]$ contains the channel gains of the links between the source, the relays and the destination, and $p_k[i] = \widetilde{C}_k h_k[i]$ is the effective signature for user k. The $(n_r+1) \times (n_r+1)$ diagonal matrix $B_k[i] = \mathrm{diag}(b_k[m_1] \ \tilde{b}_k^{r_1d}[m_2] \ldots \tilde{b}_k^{r_{n_r}d}[m_{n_p}])$ contains the symbols transmitted from the source to the destination $(b_k[i])$ and the n_r symbols transmitted from the relays to the destination $(\tilde{b}_k^{r_1d}[m_2] \ldots \tilde{b}_k^{r_{n_r}d}[m_{n_r}])$ on the main diagonal, and the $(n_r+1)M \times (n_r+1)M$ diagonal matrix $\widetilde{B}_k[i] = \mathrm{diag}(b_k[m_1] \bigotimes I_M \ \tilde{b}_k^{r_1d}[m_2] \bigotimes I_M \ldots \tilde{b}_k^{r_{n_r}d}[m_{n_p}] \bigotimes I_M)$, where $\bigotimes$ denotes the Kronecker product and I_M is an identity matrix with dimension M. The $(n_r+1) \times 1$ power allocation vector $a_k[i] = [a_{sd}^k[m_1] \ a_{r_1d}^k[m_2] \ldots a_{r_{n_r}d}^k[m_{n_p}]]^T$ has the amplitudes of the links, the $(n_r+1) \times (n_r+1)$ diagonal matrix $A_k[i]$ is given by $A_k[i] = \mathrm{diag}\{a_k[m_1]\}$, and the $(n_r+1)M \times (n_r+1)M$ diagonal matrix $\widetilde{A}_k[i] = [a_{sd}^k[m_1] \bigotimes I_M \ a_{r_1d}^k[m_2] \bigotimes I_M \ldots a_{r_{n_r}d}^k[m_{n_p}] \bigotimes I_M]^T$. The $(n_r+1)M \times (n_r+1)$ matrix P_k has copies of the effective signature $p_k[i]$ shifted down by M positions for each column and zeros elsewhere. The $(n_r+1)M \times 1$ vector $\boldsymbol{\eta}[i]$ represents the ISI terms and the $(n_r+1)M \times 1$ vector $\boldsymbol{n}[i]$ has the noise components.

3. PROPOSED BLIND RECEIVER DESIGN, POWER ALLOCATION AND CHANNEL ESTIMATION

In this section, a joint blind receiver design and power allocation strategy is proposed using the CCM approach and group-based

power constraints along with a blind channel estimator. To this end, the $(n_r+1)M \times 1$ received vector in (4) can be expressed as

$$
r[i] = P_\mathcal{S}[i] B_\mathcal{S}[i] a_{\mathcal{S},k}[i] + \sum_{k \neq \mathcal{S}} P_k[i] B_k[i] a_k[i] + \boldsymbol{\eta}[i] + \boldsymbol{n}[i], \tag{5}
$$

where $\mathcal{S} = \{\mathcal{S}_1, \mathcal{S}_2, \ldots, \mathcal{S}_G\}$ denotes the group of G users to consider in the design. The $(n_r+1)M \times G(n_r+1)$ matrix $P_\mathcal{S} = [P_{\mathcal{S}_1} \ P_{\mathcal{S}_2} \ \ldots \ P_{\mathcal{S}_G}]$ contains the G effective signatures of the group of users. The $G(n_r+1) \times G(n_r+1)$ diagonal matrix $B_k[i] = \mathrm{diag}(b_{\mathcal{S}_1}[i] \ \tilde{b}_{\mathcal{S}_1}^{r_1d}[i] \ldots \tilde{b}_{\mathcal{S}_1}^{r_nd}[i] \ \ldots \ b_{\mathcal{S}_G}[i] \ \tilde{b}_{\mathcal{S}_G}^{r_1d}[i] \ldots \tilde{b}_{\mathcal{S}_G}^{r_nd}[i])$ contains the symbols transmitted from the sources to the destination and from the relays to the destination of the G users in the group on the main diagonal, the $G(n_r+1) \times 1$ power allocation vector $a_{\mathcal{S},k}[i] = [a_{sd}^{\mathcal{S}_1}[i] \ a_{r_1d}^{\mathcal{S}_1}[i] \ldots a_{r_{n_r}d}^{\mathcal{S}_1}[i], \ \ldots, \ a_{sd}^{\mathcal{S}_G}[i] \ a_{r_1d}^{\mathcal{S}_G}[i] \ldots a_{r_{n_r}d}^{\mathcal{S}_G}[i]]^T$ of the amplitudes of the links used by the G users in the group.

3.1. Blind CCM Receiver Design and Power Allocation Scheme with Group-Based Constraints

The linear interference suppression for user k is performed by the receive filter $w_k[i] = [w_{k,1}[i], \ \ldots, \ w_{k,(n_r+1)M}[i]]$ with $(n_r+1)M$ coefficients on the received data vector $r[i]$ and yields

$$
z_k[i] = w_k^H[i] r[i], \tag{6}
$$

where $z_k[i]$ is an estimate of the symbols, which are processed by a slicer $Q(\cdot)$ that performs detection and obtains $\hat{b}_k[i] = Q(z_k[i])$.

Let us now detail the CCM-based design of the receivers for user k represented by $w_k[i]$ and for the computation of the $G(n_r+1) \times 1$ power allocation vector $a_{\mathcal{S},k}[i]$. This problem can be cast as

$$
[w_k^{\mathrm{opt}}, \ a_{\mathcal{S},k}^{\mathrm{opt}}] = \arg \min_{w_k[i], a_{\mathcal{S},k}[i]} E[(|w_k^H[i] r[i]|^2 - 1)^2]
$$
$$
\text{subject to } a_{\mathcal{S},k}^H[i] a_{\mathcal{S},k}[i] = P_G \text{ and } w_k^H[i] p_k[i] = \nu, \tag{7}
$$

where ν is a parameter used to enforce convexity [18]. The CCM expressions for the receive filter $w_k[i]$ and the power allocation vector $a_{\mathcal{S},k}[i]$ can be obtained with the method of Lagrange multipliers which transforms (7) into the Lagrangian function

$$
\mathcal{L}_k = E\Big[\Big(|w_k^H[i] \big(P_\mathcal{S}[i] B_\mathcal{S}[i] a_{\mathcal{S},k}[i]
$$
$$
+ \sum_{k \neq \mathcal{S}} P_k[i] B_k[i] a_k[i] + \boldsymbol{\eta}[i] + \boldsymbol{n}[i])|^2 - 1\Big)^2\Big] \tag{8}
$$
$$
+ \lambda_k(a_{\mathcal{S},k}^H[i] a_{\mathcal{S},k}[i] - P_G) + \rho_k(w_k^H[i] p_k[i] - \nu),
$$

where λ_k and ρ_k are Lagrange multipliers. An expression for $a_{\mathcal{S},k}[i]$ is obtained by fixing $w_k[i]$, taking the gradient terms of the Lagrangian and equating them to zero which yields

$$
a_{\mathcal{S},k}[i] = (R_{\mathcal{S},k}[i] + \lambda_k I)^{-1} d_{\mathcal{S},k}[i] \tag{9}
$$

where $R_{\mathcal{S},k}[i] = E[|z_k[i]|^2 B_\mathcal{S}^H[i] P_\mathcal{S}^H[i] w_k[i] w_k^H[i] P_\mathcal{S}[i] B_\mathcal{S}[i]]$ is a $G(n_r+1) \times G(n_r+1)$ correlation matrix and the $G(n_r+1) \times 1$ vector $d_{\mathcal{S},k}[i] = E[z_k[i] B_\mathcal{S}^H[i] P_\mathcal{S}^H[i] w_k[i]]$ is a cross-correlation vector. The Lagrange multiplier λ_k plays the role of a regularization term and has to be determined numerically due to the difficulty of evaluating its expression. Now fixing $a_{\mathcal{S},k}[i]$, taking the gradient terms of the Lagrangian and equating them to zero leads to

$$
w_k[i] = R_k^{-1}[i](d_k[i] - p_k[i] \gamma_k^{-1}[i](p_k^H[i] R_k^{-1}[i] d_k[i] - \nu)), \tag{10}
$$

where $\gamma_k[i] = p_k^H[i] R_k^{-1}[i] p_k[i]$, the correlation matrix is given by $R_k[i] = E[|z_k[i]|^2 r[i] r^H[i]]$ and $d_k[i] = E[z_k[i] r[i]]$ is a

$(n_r + 1)M \times 1$ cross-correlation vector. The quantities $\boldsymbol{R}_k[i]$ and $\boldsymbol{d}_k[i]$ depend on the power allocation vector $\boldsymbol{a}_{\mathcal{S},k}[i]$. The expressions in (9) and (10) do not have a closed-form solution as they arise from a higher-order optimization. Moreover, the expressions also depend on each other and require the estimation of the channel vector $\boldsymbol{h}_k[i]$. Thus, it is necessary to iterate (10) and (9) with initial values to obtain a solution and to estimate the channel. The network has to convey the information from the group of users necessary to compute the group-based power allocation including the filter $\boldsymbol{w}_k[i]$. The expressions in (10) and (9) require matrix inversions with cubic complexity ($O(((n_r + 1)M)^3)$ and $O((K(n_r + 1))^3)$).

3.2. Blind Cooperative Channel Estimation

In order to blindly estimate the channel in the cooperative system under study, let us consider the covariance matrix $\boldsymbol{R} = E[\boldsymbol{r}[i]\boldsymbol{r}^H[i]]$ and the transmitted signal $\boldsymbol{x}_k[i] = \boldsymbol{A}_k[i]\boldsymbol{B}_k[i]\boldsymbol{p}_k[i]$. Let us now perform an eigen-decomposition on $\boldsymbol{R}$

$$
\begin{aligned}
\boldsymbol{R} &= \sum_{k=1}^{K} E[\boldsymbol{x}_k[i]\boldsymbol{x}_k^H[i]] + E[\boldsymbol{\eta}[i]\boldsymbol{\eta}^H[i]] + \sigma^2 \boldsymbol{I} \\
&= [\boldsymbol{\phi}_s \ \boldsymbol{\phi}_n] \begin{bmatrix} \boldsymbol{\Lambda}_s + \sigma^2 \boldsymbol{I} & \boldsymbol{0} \\ \boldsymbol{0} & \sigma^2 \boldsymbol{I} \end{bmatrix} [\boldsymbol{\phi}_s \ \boldsymbol{\phi}_n]^H,
\end{aligned} \tag{11}
$$

where $\boldsymbol{\phi}_s$ and $\boldsymbol{\phi}_n$ are the signal and noise subspaces, respectively. Since $\boldsymbol{\phi}_s$ and $\boldsymbol{\phi}_n$ are orthogonal, we have the condition $\boldsymbol{\phi}_n^H \boldsymbol{x}_k[i] = \boldsymbol{\phi}_n^H \boldsymbol{A}_k[i]\boldsymbol{B}_k[i]\boldsymbol{p}_k[i] = \boldsymbol{\phi}_n^H \boldsymbol{A}_k[i]\boldsymbol{B}_k[i]\boldsymbol{C}_k\boldsymbol{h}_k[i] = \boldsymbol{0}$ and hence

$$
\Gamma = \boldsymbol{h}_k^H[i] \underbrace{\boldsymbol{C}_k^H \boldsymbol{B}_k^H[i]\boldsymbol{A}_k^H[i]\boldsymbol{\phi}_n \boldsymbol{\phi}_n^H \boldsymbol{A}_k[i]\boldsymbol{B}_k[i]\boldsymbol{C}_k}_{\boldsymbol{\Upsilon}_k} \boldsymbol{h}_k[i] \tag{12}
$$

The above relation allows to blindly estimate the channel $\boldsymbol{h}_k[i]$. To this end, we need to compute the eigenvector corresponding to the smallest eigenvalue of $\boldsymbol{\Upsilon}_k$. It turns out that we can use the fact that $\lim_{p \to \infty} (\boldsymbol{R}/\sigma^2)^{-p} = \boldsymbol{\phi}_n \boldsymbol{\phi}_n^H$ [18] and, in practice, it suffices to use $p = 1$ or 2. Therefore, to blindly estimate the channel of user k in the cooperative system we need to solve the optimization problem

$$
\hat{\boldsymbol{h}}_k[i] = \arg \min_{\boldsymbol{h}_k[i]} \boldsymbol{h}_k^H[i] \boldsymbol{\Upsilon}_k \boldsymbol{h}_k[i], \ \text{subject to} \ ||\boldsymbol{h}_k[i]|| = 1, \tag{13}
$$

In what follows, computationally efficient algorithms based on an alternating optimization strategy will be detailed.

4. PROPOSED ADAPTIVE ALGORITHMS

In this section, we develop joint adaptive RLS-type algorithms using an alternating optimization strategy for efficiently estimating the parameters of the receive filters, the power allocation vectors and the channels. Note that the proposed algorithms did not have problems with local minima and converge to the desired solutions.

The first task in the proposed scheme is to build the group of G users that will be used for the power allocation and receive filter design. A RAKE receiver is employed to obtain $z_k^{\text{RAKE}}[i] = (\boldsymbol{C}_k \hat{\boldsymbol{h}}_k[i])^H \boldsymbol{r}[i] = \hat{\boldsymbol{p}}_k^H[i]\boldsymbol{r}[i]$ and the group is formed according to

$$
\text{compute the } G \text{ largest } |z_k^{\text{RAKE}}[i]|, \ k = 1, 2, \ldots, K. \tag{14}
$$

The design of the RAKE and the other tasks require channel estimation. In order to solve (13) efficiently, a variant of the power method [16] that uses a simple shift is adopted

$$
\hat{\boldsymbol{h}}_k[i] = (\boldsymbol{I} - \tau_k[i]\hat{\boldsymbol{\Upsilon}}_k[i])\hat{\boldsymbol{h}}_k[i-1], \tag{15}
$$

where $\tau_k[i] = 1/tr[\hat{\boldsymbol{\Upsilon}}_k[i]]$ and $\hat{\boldsymbol{h}}_k[i] \leftarrow \hat{\boldsymbol{h}}_k[i]/||\hat{\boldsymbol{h}}_k[i]||$ to normalize the channel. The quantity $\hat{\boldsymbol{\Upsilon}}_k[i]$ is estimated by $\hat{\boldsymbol{\Upsilon}}_k[i] =$

$\alpha \hat{\boldsymbol{\Upsilon}}[i-1] + \boldsymbol{C}_k^H \hat{\boldsymbol{B}}_k^H[i]\hat{\boldsymbol{A}}_k^H[i]\hat{\boldsymbol{R}}^{-p}[i]\hat{\boldsymbol{A}}_k[i]\hat{\boldsymbol{B}}_k[i]\boldsymbol{C}_k$, where α is a forgetting factor that should be close to 1 and $\hat{\boldsymbol{R}}^{-p}[i]$ is computed with the matrix inversion lemma. The power allocation and receive filter design problems outlined in (7) are solved by replacing the expected values in (9) and (10) with time averages, and RLS-type algorithms. The approach for allocating the power within a group is to drop the constraint, estimate the quantities of interest and then impose the constraint via a subsequent normalization. The group-based power allocation is computed by

$$
\hat{\boldsymbol{a}}_{\mathcal{S},k}[i] = \hat{\boldsymbol{P}}_{\mathcal{S},k}[i-1]\hat{\boldsymbol{d}}_{\mathcal{S},k}[i], \tag{16}
$$

where

$$
\hat{\boldsymbol{d}}_{\mathcal{S},k}[i] = \alpha \hat{\boldsymbol{d}}_{\mathcal{S},k}[i] + z_k[i]\boldsymbol{v}_k[i], \tag{17}
$$

$$
\boldsymbol{k}_{\mathcal{S},k} = \frac{\alpha^{-1}\hat{\boldsymbol{P}}_{\mathcal{S},k}[i-1]z_k[i]\boldsymbol{v}_k[i]}{1 + \alpha^{-1}\boldsymbol{v}_k^H[i]\hat{\boldsymbol{P}}_{\mathcal{S},k}[i-1]\boldsymbol{v}_k[i]|z_k[i]|^2}, \tag{18}
$$

$$
\hat{\boldsymbol{P}}_{\mathcal{S},k}[i] = \alpha^{-1}\hat{\boldsymbol{P}}_{\mathcal{S},k}[i-1] - \alpha^{-1}z_k^*[i]\boldsymbol{k}_{\mathcal{S},k}[i]\boldsymbol{v}_k^H[i]\hat{\boldsymbol{P}}_{\mathcal{S},k}[i-1]. \tag{19}
$$

The normalization $\hat{\boldsymbol{a}}_{\mathcal{S},k}[i] \leftarrow P_G \ \hat{\boldsymbol{a}}_{\mathcal{S},k}[i]/||\hat{\boldsymbol{a}}_{\mathcal{S},k}[i]||$ is then made to ensure the power constraint. The receive filter is computed by

$$
\hat{\boldsymbol{w}}_k[i] = \boldsymbol{P}_k[i](\hat{\boldsymbol{d}}_k[i] - \hat{\boldsymbol{p}}_k[i]\hat{\gamma}_k^{-1}[i](\hat{\boldsymbol{p}}_k^H[i]\hat{\boldsymbol{P}}_k[i]\hat{\boldsymbol{d}}_k[i] - \nu), \tag{20}
$$

where $\gamma_k^{-1}[i] = \hat{\boldsymbol{p}}_k^H[i]\hat{\boldsymbol{P}}_k[i]\hat{\boldsymbol{p}}_k[i]$ and

$$
\hat{\boldsymbol{d}}_k[i] = \alpha \hat{\boldsymbol{d}}_k[i] + z_k[i]\boldsymbol{r}[i], \tag{21}
$$

$$
\boldsymbol{k} = \frac{\alpha^{-1}\hat{\boldsymbol{P}}_k[i-1]z_k[i]\boldsymbol{r}[i]}{1 + \alpha^{-1}\boldsymbol{r}^H[i]\hat{\boldsymbol{P}}_k[i-1]\boldsymbol{r}[i]|z_k[i]|^2}, \tag{22}
$$

$$
\hat{\boldsymbol{P}}_k[i] = \alpha^{-1}\hat{\boldsymbol{P}}_k[i-1] - \alpha^{-1}z_k^*[i]\boldsymbol{k}[i]\boldsymbol{r}^H[i]\hat{\boldsymbol{P}}_k[i-1]. \tag{23}
$$

The proposed scheme employs the algorithm in (14) to allocate the users in the group and the channel estimation approach of (15). The alternating optimization strategy uses the recursions (16)-(23) with 1 or 2 iterations per time instant i.

5. SIMULATIONS

The bit error ratio (BER) performance of the proposed blind joint power allocation and interference suppression (BJPAIS) scheme and algorithms with group-based constraints (GBC) is assessed. The BJ-PAIS scheme and algorithms are compared with blind schemes without cooperation (BNCIS) [16] and with cooperation (CIS) using an equal power allocation across the relays (the power allocation in the BJPAIS scheme is disabled). A DS-CDMA network with randomly generated spreading codes and a processing gain $N = 16$ is considered. The fading channels are generated considering a random power delay profile with gains taken from a complex Gaussian variable with unit variance and mean zero, $L = 5$ paths spaced by one chip, and are normalized for unit power. The power constraint parameter $P_{A,k}$ is set for each user so that one can control the SNR (SNR $= P_{A,k}/\sigma^2$) and $P_T = P_G + (K - G)P_{A,k}$, whereas it follows a log-normal distribution for the users with associated standard deviation equal to 3 dB. The DF cooperative protocol is adopted and all the relays and the destination terminal use linear CCM receivers.

The first experiment depicted in Fig. 1 shows the BER performance of the proposed BJPAIS scheme and algorithms against the BNCIS and BCIS schemes with $n_r = 2$ relays. The BJPAIS scheme is considered with the group-based power constraints (BJPAIS-GBC). All techniques employ RLS-type algorithms for estimation of the channels, the receive filters and the power allocation for each user. The results show that as the group size G is increased the proposed BJPAIS scheme and algorithms converge to approximately the same level of the cooperative training-based JPAIS-MMSE scheme reported in [11], which employs $G = K$ for power allocation, and has full knowledge of the channel and the noise variance.
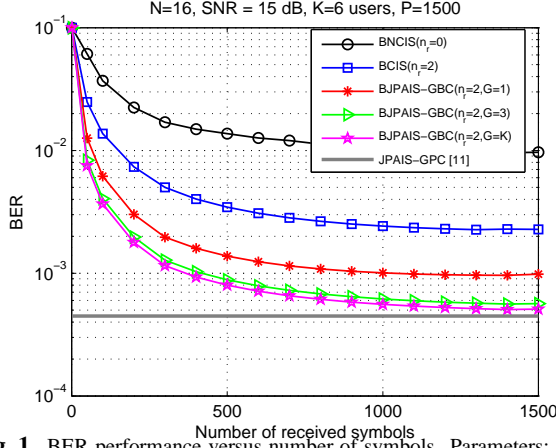
Fig. 1. BER performance versus number of symbols. Parameters: $p = 1$, $\lambda_T = \lambda_k = 0.025$ (for MMSE and CCM schemes), $\alpha = 0.998$, $\hat{\boldsymbol{P}}_{\mathcal{S},k}[i] = 0.01\boldsymbol{I}$ and $\hat{\boldsymbol{P}}_k[i] = 0.01\boldsymbol{I}$.

The proposed BJPAIS-GBC scheme is then compared with a non-cooperative approach (BNCIS) and a cooperative scheme with equal power allocation (BCIS) across the relays for $n_r = 1, 2$ relays. The results shown in Fig. 2 illustrate the performance improvement achieved by the BJPAIS scheme and algorithms, which significantly outperform the BCIS and the BNCIS techniques. As the number of relays is increased so is the performance, reflecting the exploitation of the spatial diversity. In the scenario studied, the proposed BJPAIS-GBC with $G = 3$ can accommodate up to 3 more users as compared to the BCIS scheme and double the capacity as compared with the BNCIS for the same BER performance, without the need for training data. The curves indicate that the GBC for power allocation with only a few users is able to attain a performance close to the BJPAIS-GBC with $G = K$ users, while requiring a lower complexity and extra network signalling. A detailed study of the signalling requirements will be considered in a future work.
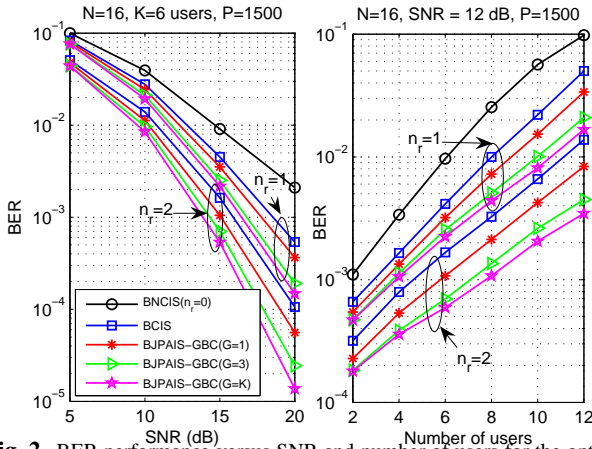

Fig. 2. BER performance versus SNR and number of users for the optimal linear MMSE detectors. Parameters: $p = 1$, $\alpha = 0.998$, $\hat{\boldsymbol{P}}_{\mathcal{S},k}[i] = 0.01\boldsymbol{I}$ and $\hat{\boldsymbol{P}}_k[i] = 0.01\boldsymbol{I}$.

6. CONCLUSIONS

This work has proposed the BJPAIS scheme for cooperative DS-CDMA networks with multiple relays and the DF protocol. A CCM design for the receive filters and the power allocation with group

constraints has been devised along with a blind channel estimator and RLS-type algorithms. The results have shown that the BJPAIS scheme achieves significant gains in performance and capacity over existing schemes, without requiring training data. Future work will consider distributed space-time coding and synchronization.

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